REPORT DOCUMENTATION PAGE

AFRL-SR-BL-TR-99-

0114

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPO...
		01 Sep 98 to 28 Feb 99 Final

4. TITLE AND SUBTITLE
(STTR 98 Phase 1) Combat simulation analysis of advanced technology weapons

5. FUNDING NUMBERS
65502F
STTR/TS

6. AUTHOR(S)
Dr Hamilton

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
HPS Simulations
P O Box 3245
Santa Clara, CA 95055-3245

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NE
801 North Randolph Street Rm 732
Arlington, VA 22203-1977

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
F49620-98-C-0080

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
APPROVAL FOR PUBLIC RELEASED; DISTRIBUTION UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This Phase 1 work demonstrated the feasibility of developing flexible computer models capable of performing reasonable combat prediction and analysis. In addition to producing accurate combat results for existing weapons, the software also is capable of modeling hypothetical or potential systems which could incorporate various advanced technology weapons.

14. SUBJECT TERMS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

AF98T005

Combat Analysis of Advanced Technology Weapons Concepts

Final Report

HPS Simulations

9 April, 1999

Principal Investigator:
Scott S. Hamilton
HPS Simulations
PO Box 3245
Santa Clara CA 95055-3245
(408) 554-8381
(408) 241-6886 (FAX)
email: hpssims@compuserve.com
web: www.hpssims.com

Research Partner/Institution:
Dr. Michael A. Palmer
East Carolina University
Brewster A-228
Greenville NC 27858
(919) 328-6086

Period Covered: 1 Sep 98 - 28 Feb 99

1. Introduction

Computer combat simulation provides an efficient and cost effect method of evaluating weapons and force performance. Based on increasingly sophisticated models, these simulations can encompass land, sea, air, forces, and account for a wide array of interrelationships between divergent weapons systems within potential electronic, nuclear, and chemical warfare environments.

Computer simulations can also be used to evaluate the effects of emerging technologies, whether actual or hypothetical. This enables military planners to gain a better idea of the expected effectiveness of such a system, and whether or not it meets the specified requirements before expending large amounts of time and money in further development.

2. Project Objectives

The overall objective of this Phase I work was to demonstrate the feasibility of developing flexible computer models capable of performing reasonable combat prediction and analysis. In addition to producing accurate combat results for existing weapons, the software also had to demonstrate it was capable of modeling hypothetical or potential systems which could incorporate various advanced technology weapons.

3. Work Carried Out

The research was broken down into 3 primary areas:

a) Database development.
b) Model damage from current weapon types.
c) Model damage and other effects from Advanced Technology weapon systems.

<u>Database Development</u>

All computer wargames are based on a series of relational databases. These databases store information on every major aspect of the simulation, including the terrain, the weapons involved, and the maneuver units. As such, the database structures are absolutely critical for the successful operation of the program. Ultimately, they are the limiting factor in determining the accuracy and depth of the simulation. However, there is a limit to the amount of information that can be reasonably entered and accessed. The database structures developed for Phase I achieve a near optimum balance between these competing interests.

This is a summary of the databases developed for use in the Phase I project:

Terrain and Map Value Databases	
Hex Data	Information for each hex on the map, including what types of terrain are in the hex, and the presence of rivers, roads, cities, and other man-made features (bridges, obstacles, etc.).
Terrain Effects	The physical effects of each type of terrain, including effects on movement, blocking of the line of sight (LOS), protective effects against enemy fire, and flammability.
Weather Types	Standard weather and seasonal characteristics such as maximum sighting range, foliage levels, and dust generation from movement.
Atmosphere Types	General atmospheric conditions, such as temperature, wind, cloud characteristics, and precipitation level.

Engineering/Man-Made Object Databases	
Bridges	Bridge information includes carrying capacity, length, width, construction type and resistance to damage effects.
Improved Positions	Improved positions are described by their construction material, their dimensions and wall thickness, the types of units that can occupy the position, the open (firing) arc, and overhead cover.
Minefields	Minefields are rated for the number of types of mines they contain. The mines themselves are described by their type (AP, AT, Naval, etc.) and their standard effects (burst radius, armor penetration, etc.).
Obstacles	The obstacles database includes all man-man objects intended to slow or prevent movement. These objects include, but are not limited to, barbed wire and concertina, tank ditches, log hurdles, abatis, tetrahedrons and dragon's teeth. Each of these obstacles has a link back to the Terrain Effects database to specify its effects on each different movement type.
Engineer Systems	Engineering systems are used (by specially equipped units) to place, repair or remove obstacles, minefields, improved positions, roads and bridges. Data fields include the types of actions the system can perform, how long each action takes, and how effective it is.

Maneuver Unit Database	
Units	Units are one or more weapons systems grouped together into a single entity for command and movement purposes. Units are normally of platoon/flight size, but can be comprised of a single weapon. Unlike the other databases in which the data is fixed, much of the unit data is dynamic and changes as the battle progresses. Some of the data contained in the unit structure include the types of weapons system(s) that make up the unit and their quantity, amount of ammunition on hand, where the unit is moving and where it is facing, what sort of damage it has suffered, what targets it is engaging, its current status with regard to morale, training, camouflage and other categories, and its current SOP or "default" orders.

Weapons Systems Databases	
Ammunition Models	The ammunition database includes all of the physical properties for each model of ammunition. Some of these values are the shell weight, muzzle velocity, size, composition, and the air drag coefficient. The database also rates each ammunition type on its damage potential and secondary effects (flammability, cratering, etc.).
Ammunition Types	Each ammunition model must belong to a general munition type. The type includes data on how the munition causes damage (penetration, explosion, etc.), how the munition is guided, if the guidance can be jammed, and other unique characterisics (always hits top, cluster muntion, chemical, remote sensor, etc.).
Guns/Launchers	The gun or launcher data includes links to the specific ammunition models the gun fires, along with a general accuracy rating and any special firing characteristics (backblast, flash, smoke, noise, etc.).
Armor Types	Armor is any material which is used to hinder the penetration of a projectile, and armor types include metallic alloys, plate, composites, earth, wood, masonry, and other materials. This database stores the physical properties of each armor type, and includes values such as the armor density, yield strength, the Brinell Hardness Number. It also includes a number of special dissipation rating to model laminates and other special composite materials.
Weapons Systems	Weapons Systems are single, indivisible entities which are used to create units and higher formations. They include tanks, guns, infantrymen, aircraft and ships. In the relational database format, each weapons system can be linked to a number of other tables including the armor data, the gun/launcher data, the engineering systems data, and the special systems (radar, PMD, decoy systems, etc.). In addition to these links, the weapons system data includes speed and cargo values, exact armor configurations, size and proportions, system weight, mountings for the gun/launcher subsystems, and a number of other specific info.

Special Systems Databases	
Radar Systems	Radar systems are rated by their range, resolution, types of targets that can be detected, operating mode, and resistance to ECM.
Decoy Systems	The decoy system data includes the type of detection system the decoy will defeat (heat seeking, radar, sound seeking, etc.) and its general effectiveness.
PMD Systems	PMD (Point Missile Defense) systems are used by weapons systems to defend against incoming missiles and projectiles. They are rated by the types of incoming projectiles they can engage, their maximum detection range and detection effectiveness, the time required to engage a target after detection, their firing arc, and how susceptible they are to damage from enemy fire.
Laser Systems	This table includes data for laser systems used for target designation, including the type of laser, its range, and how it is affected by conditions such as smoke and precipitation. Lasers used for destruction and damage in their own right are entered in the Energy Weapons database.
Sensor Systems	The remote sensor database includes data describing the type (visual, audio, electromagnetic, motion, etc.) and effectiveness of the sensor, including its sensitivity, accuracy, and transmitting range. Remote sensors are normally linked to specific ammunition models, which allow them to be placed by artillery or aircraft.
Energy Weapons	Advanced energy type weapons are defined in this table. The data fields include the energy type, the peak frequency, bandwidth, maximum power and distribution, the pulse and recharge times, the beam width, and the effects the weapon has on various targets.

Model Damage From Current Weapon Types

Solid projectile penetration is determined from equations summarized in "High Velocity Impact Dynamics" by Dr. Jonas Zukas These equations are derived by assuming that non-deforming projectiles penetrate though an action of displacing and compressing target material (work), and that this penetration is resisted by a force dependent on the properties of the target material.

Several researchers have developed models using variations on the basic force/work approach. These models are: Robbins-Euler, Poncelet, Poncelet-Helle, Nishiwaki, Burkhardt, Jacobson, and Recht. The following table shows the equations for these models (reprinted from Zukas):

Robins–Euler $$\int_0^x \frac{A_x}{A_p}\,dx = \frac{(M/2A_p)(V_0^2 - V^2)}{p_d}$$

Poncelet $$\int_0^x \frac{A_x}{A_p}\,dx = \frac{M/2A_p}{C_\alpha \rho}\ln\frac{V_0^2 + p_d/(C_\alpha \rho)}{V^2 + p_d/(C_\alpha \rho)}$$

Poncelet–Helie $$\int_0^x \frac{A_x}{A_p}\,dx = \frac{M/2A_p}{c}\left[\ln\frac{(V_0 + b/2c)^2 + n}{(V + b/2c)^2 + n} + \frac{bk}{n^{1/2}}\left(\tan^{-1}\frac{V + b/2c}{n^{1/2}} - \tan^{-1}\frac{V_0 + b/2c}{n^{1/2}}\right)\right]$$
$a = p_d,\ b = \mu C_{\alpha 2}/\sqrt{A_p},\ c = C_{\alpha 1}\rho,\ n = a/c - (b/2c)^2$

Nishiwaki[b] $$\int_0^x \frac{A_x}{A_p}\,dx = \frac{M/2A_p}{\rho \sin^2\alpha}\ln\frac{V_0^2 + p_d/2\rho \tan\alpha \sin^2\alpha}{V^2 + p_d/2\rho \tan\alpha \sin^2\alpha}$$

Burkhardt[b] $$\int_0^x \frac{A_x}{A_p}\,dx = \frac{M/2A_p}{\rho/2}\ln\frac{V_0^2 + 2[0.8\sigma_{eu}(1 + f/\tan\alpha)(3 - 4\nu)/\rho(2 - 4\nu)]}{V^2 + 2[0.8\sigma_{eu}(1 + f/\tan\alpha)(3 - 4\nu)/\rho(2 - 4\nu)]}$$

Jacobson[c] $$\int_0^x \frac{A_x}{A_p}\,dx = \frac{2(M/2A_p)}{\rho \sin^2\alpha(\tan\alpha + f)}\ln\frac{V_0^2 + 2\sigma_c/\rho \sin^2\alpha \tan\alpha}{V^2 + 2\sigma_c/\rho \sin^2\alpha \tan\alpha}$$

Recht[b] $$\int_0^x \frac{A_x}{A_p}\,dx = \frac{2(M/2A_p)}{C_n b}\left[(V_0 - V) - \frac{a}{b}\ln\frac{a + bV_0}{a + bV}\right]$$
$a = 2\tau_s \ln(2Z_m)(1 + f/\tan\alpha),\ b = C_c\sqrt{K\rho}\,(1 + f/\tan\alpha)\sin\alpha$

M = mass of penetrator, V_0 = initial velocity (i.e., $V_0 = V$, where $x = 0$),
x = penetration distance (i.e., change in position while V_0 diminishes t

[a] See Table 1 for other definitions (k is defined in the footnote to Table 1). Solutions of motion equation, $F = M dV/dt = MV dv/dx$, using force definitions given in Table 1).
[b] For standard ogives, i.e., where $1 \le$ CRH ≤ 8, use $\alpha = 23.5°$; for $\alpha > 37.5b°$, use $\alpha = 37.5°$.
[c] This equation only considers force acting on nose. Jacobson adds a friction force which acts on cylindrical body (Jacobson, 1975).

The following graph illustrates how these models compare to experimental data (from Zukas):

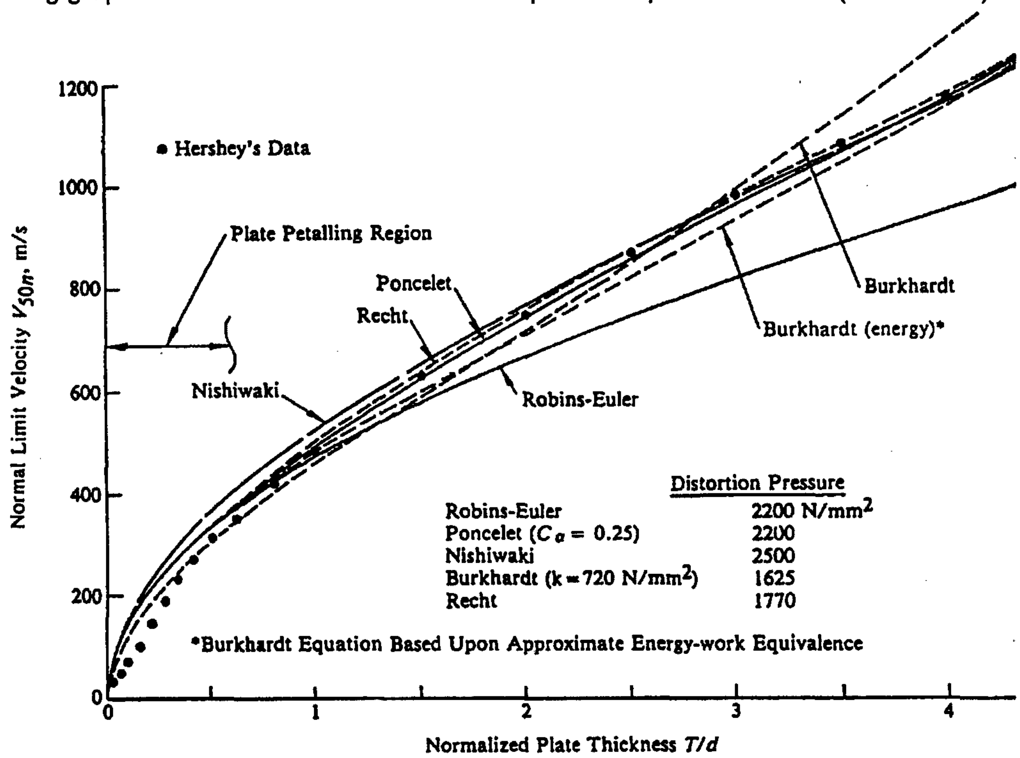


FIGURE 17 Relating penetration equations to limit velocity data: 3-in. (76-mm) AP M79 versus steel plate (230 BHN).

After considering the correlation to the experimental results, as well as the ease of calculation, we determined that the Poncelet model provides the best method of calculating penetration for the simulation. The $\mathbf{P_d}$ constant, which represents the Distortion Pressure, must be determined for each individual case based primarily on the properties of the target and projectile media. Zukas does not provide a model for this, so we derived our own relationship for this value based on finding a "best fit" for known projectile penetration values:

$$\mathbf{P_d} = 2.2 \times 10^9 \times A \times B$$

Where:

A = armor density factor normalized to steel plate = $\mathbf{d_a}$ / 7830

B = relative force distribution = $4\ \mathbf{d_a}\,\mathbf{h_a} / \mathbf{d_p}\,\mathbf{h_p}$

and

$\mathbf{d_a}$ = density of the armor
$\mathbf{d_p}$ = density of the projectile
$\mathbf{h_a}$ = hardness of the armor
$\mathbf{h_p}$ = hardness of the projectile

For steel plate armor (density = 7830) and $\mathbf{d_p}\,\mathbf{h_p} = 4\ \mathbf{d_a}\,\mathbf{h_a}$, $\mathbf{P_d} = 2.2 \times 10^9$ - the value used for the calculation shown in Figure 17.

One a projectile has been determined to partially or fully penetrate the target armor, a damage assessment is made based on the type of target and its resistance to damage rating, whether or not the impact creates spall, and the projectile's damage properties.

Additional calculations are performed to determine special conditions such as the projectile's velocity after the nose cone penetration, and the probabilities of petalling or catastrophic target material failure (shatter or fracture).

Model Damage/Effects From Advanced Technology Weapon Systems

Advanced/Energy weapons inflict damage without the physical impact of a projectile (or sub projectile) or blast wave on the target. Instead, these weapons cause destruction by overloading specific components of the target system, and causing them to fail in some way. These sub-system failures then degrade the target system performance or completely incapacitate it. Generally, these weapons are designed to affect sensitive critical components such as electronics, optical systems, and sensors.

Types of Advanced/Energy Weapons

The simulation model subdivides Advanced/Energy weapons into 13 categories. Twelve of these types represent electromagnetic energy in various frequency ranges. The other two types are particle beams, and plasma beams.

The electromagnetic spectrum is broken down by frequency as follows:

	Frequency (in Hz) (*E* is a power of 10, i.e. 1.0 *E6* = 1million)
Long Wave (Radio)	1 to 1.0 *E6*
AM (Radio)	1.0 *E6* to 1.0 *E7*
Short Wave (Radio)	1.0 *E7* to 2.9 *E9*
Microwave Low	2.9 *E9* to 1.0 *E10*
Microwave Medium	1.0 *E10* to 7.0 *E10*
Microwave High	7.0 *E10* to 3.0 *E11*
Infra-Red	3.0 *E11* to 4.0 *E15*
Visible Light	4.0 *E15* to 8.0 *E15*
Ultra-Violet	8.0 *E15* to 3.0 *E17*
X Ray	3.0 *E17* to 1.0 *E21*
Gamma Ray	1.0 *E21* and up

Note: The boundaries of the various frequency groups are arbitrary, as is the nomenclature. For example, there is no specific "AM Radio" band. However, because commercial AM radio stations in the US are assigned to these frequencies, this term is commonly used to describe this portion of the EM spectrum.

Particle and plasma beams are not part of the electromagnetic spectrum and do not have a meaningful frequency. This is because they accelerate and "fire" actual particles (with a rest mass greater than zero) at the target instead of just radiating energy.

The power ratings and other characteristics for specific Advanced/Energy weapon systems are set in the Advanced/Energy Weapon Data Editor.

<u>"Firing" Advanced/Energy Weapons</u>

Advanced/Energy Weapons are classified as "ammunition types", and are fired from gun/launcher systems the same as normal physical ammunition. However, energy emitted by these weapons radiates out from their source in straight lines (i.e., gravity, air drag, etc., have no effect on them). The "width" determines the divergence of the energy rays, resulting in a cone shaped pattern. "Pure" beams of zero width have no dispersion - they are assumed to have a constant cross-section area of 1 square cm. In the simulation, the ground completely blocks all forms of energy. The target does not need to be visible, however. The line of sight (LOS) along the path can be blocked to vision without necessarily blocking the energy beam.

Advanced/Energy weapons, with the exception of pure beams, do not need to be aimed at a specific target. They can be fired at (and affect) any hex location within range, whether it is occupied by a known enemy unit or not.

The same basic firing procedure is used for Advanced Weapons as for other types of ammunition, with a few modifications to better represent their special characteristics:

1) The "impact area" of the beam is determined by the beam's width, it's maximum effective range, and the characteristics of the firing unit. All units (friendly or enemy) within this area will be subjected to the effects of the weapon. For pure beams (no dispersion), the impact area is always an area equal to 1 square cm on the target surface.

2) For each potential target in the "impact area", a straight line path is calculated between it and the firing unit/beam source. If the path intersects the ground, the target is assumed to be shielded from the beam effects, and the rest of the sequence is aborted. This applies equally to friendly as well as enemy units.

Steps 3-7 are followed for each target in the "impact area":

3) The beam power is reduced by the effects of dispersion. The power decreases by a standard factor equal to the reciprocal of the square root of the range. Pure beams (with a dispersion angle of zero) are not affected by this calculation, but they can be reduced by atmospheric and other effects, as described below.
4) The power is decreased by the atmosphere and other physical obstructions encountered along the energy's travel path. The amount of the reduction is based on the firing unit and target elevations, the atmospheric conditions, intervening terrain, improved positions, protective armor and other factors. Additionally, all target units create a "shadow" behind them which may shield potential targets downrange.
5) The final power is applied to the target, and the damage probabilities for each sub-system are determined based on the individual damage values. All probabilities are based on a standard 1 μs pulse duration.
6) Using the damage probabilities from step 5, the actual damages to the different sub-systems within the target are determined. The probability is adjusted for the actual pulse duration. If the pulse is less than 1 μs, the probability is reduced proportionally. For example, if the damage probability is 50%, a pulse of ½ μs will reduce the probability to 25%. If the pulse is greater than 1 μs, it is increased as a power function of the duration difference: 1 - [(1- p) to the power d], where p is the probability and d is the duration. As an example, if the base probability is 75% and the pulse duration is 2 μs, the actual damage probability is 93.75% . If the duration would have been 3 μs, the probability would be 98.4%.
7) If the energy pulse causes detonation of explosive components (such as reactive armor, or ammunition), the subsequent effects of these explosions on the target are calculated using the standard explosive damage routines.

Damage from Advanced/Energy Weapons

Advanced/Energy Weapons primarily affect "soft" component systems. By knocking them out, the target can be seriously degraded in performance, sometimes to the point where it becomes mission ineffective. Advanced/Energy Weapons have different effects based on the weapon itself and the target type. The specific effects are determined by the target system under consideration:

Ammunition/Missiles
• The frequency of the Advanced/Energy weapon is compared to the ammunition's "Peak Susceptibility" frequency range. If it falls outside the range, no damage occurs. • Power is always reduced for the target's armor against ammunition stored internally. It is not reduced by armor for ammunition carried externally, such as aircraft ordinance, missiles, and reactive armor/PMD systems. • The total power is adjusted for variance from the "peak" frequency (no adjustment occurs if the weapon frequency equals the "peak" frequency). • The area of energy absorption depends on the type of damage inflicted: To damage guidance systems an area of 1000 sq. cm is used. To determine if the energy detonates the round, the area is calculated as the ammunition caliber/10 (sq. cm). • The adjusted power is compared to the munition's value of incoming power required for a 100% probability of "knock-out", and the actual probability of is determined as a straight line (proportional) function. • A random determination is made to see if the munition is "knocked-out" If it is, it may also be detonated depending on the values for the specific munition. If it is detonated, secondary effects of the explosion are determined using the standard damage routines. Otherwise, the munition is simply removed from the unit's on-hand stock in the scenario. • If the ammunition/missile is guided, the guidance system may also be vulnerable to advanced weapons. Vulnerability is set individually for each guided ammunition/missile model. • Missiles and other munitions may be detonated or have their guidance system knocked out while in flight (the results are applied immediately - before they progress further towards their target) • Peak Susceptibility ratings are set in the Ammunition Data Editor.

Guns/Missile Launchers
• The frequency of the Advanced/Energy weapon is compared to the gun/launcher's "Peak Susceptibility" frequency range. If it falls outside the range, no damage occurs. • Power is always reduced for the target's armor against guns or launchers mounted internally. However, the armor does not protect external systems. • The area of the gun system which absorbs energy is 1000 sq. cm. • The total power is adjusted for variance from the "peak" frequency (no adjustment occurs if the weapon frequency equals the "peak" frequency). • The adjusted power is compared to the gun/launcher's value of incoming power required for a 100% probability of "knock-out", and the actual probability is determined as a straight line (proportional) function. • A random determination is made to see if the gun/launcher is "knocked-out". • Peak Susceptibility ratings are set in the Gun/Launcher Data Editor.

Radar Systems
• The frequency of the Advanced/Energy weapon is compared to the radar system's "Peak Susceptibility" frequency range. If it falls outside the range, no damage occurs. • Advanced weapon power against radar systems is never reduced for the target's armor. • The total power is adjusted for variance from the "peak" frequency (no adjustment occurs if the weapon frequency equals the "peak" frequency). • The "size" of the radar system which absorbs energy is assumed to be 10,000 sq. cm. • The adjusted power is compared to the radar's value of incoming power required for a 100% probability of "knock-out", and the actual probability of destruction is determined using a straight line (proportional) function. • A random determination is made to see if the radar is knocked out. If it is not, it may be temporarily damaged (overloaded). The probability of being temporarily damaged is 2 times the normal "knock-out" probability. Radar systems that are temporarily damaged are checked by the computer once per turn to see if they come back "on-line." The probability of returning to service is equal to 50% of the owning force's training level. • Peak Susceptibility ratings are set in the Radar System Data Editor. • Plasma and particle beam weapons do not have a frequency. They damage and destroy radar systems using the "other electronics" category of damage, as described under Weapons Systems, below.

Weapons Systems
• Advanced weapons effects against weapons systems are applied against three major functional equipment groups: communications, fire control, and other electronics (ECM,ECCM). Damage against each equipment group is determined separately. Special Systems such as PMD, electronic decoys, and lasers may also be damaged. • The absorption areas for each equipment group are: Communications = 800 sq. cm; Fire Control = 1200 sq. cm; Other Electronics = 1000 sq. cm.; Special Systems = 1000 sq. cm. • The frequency of the Advanced/Energy weapon is compared to the equipment group's "Peak Susceptibility" frequency range. If it falls outside the range, no damage occurs. • Power is always reduced for the target's armor. • The total power is adjusted for variance from the "peak" frequency (no adjustment occurs if the weapon frequency equals the "peak" frequency). • The adjusted power is compared to the equipment group's value of incoming power required for a 100% probability of "knock-out", and the actual probability of is determined as a straight line (proportional) function. • A random determination is made to see if the group is "knocked-out", based on the damage probability from the step above.. • Effects of knocking out equipment groups are: 1) Communications: The following effects are applied as long as at least one weapons system in a unit has it's communication knocked out: Orders for the unit take 50% longer to disseminate and morale losses are increased by 10%. The "targeting efficiency" is reduced by 50% (targeting efficiency measures how effective the unit is in preventing multiple friendly units from firing at the same target). If the unit is a HQ, it will be replaced in the chain of command. 2) Fire control: The rate of fire is decreased by 25% and any weapons system accuracy adjustment is eliminated. 3) Other Electronics: ECM/ECCM, GPS, and sensor capabilities are eliminated. • The energy is also applied to a **<u>single</u>** intact and operative Special System (PMD, laser, electronic decoy) to see if it is knocked out. Special Systems use the same frequency, band width, and energy susceptibility values as the Other Electronics equipment group. Weapons system vulnerability values are set individually for each weapons system in the

Weapons System Data Editor.

Blocking and Degrading of Advanced/Energy Weapons

Armor systems and other physical objects can reduce or completely block Advanced/Energy Weapons. In this case, armor systems include "standard" armor such as steel and other metals, as well as earth, wood and concrete. The armor system may also take into account specialized systems such as magnetic deflection fields which could be used against charged plasma beams, for example. Additionally, terrain, weather and atmospheric effects can also degrade certain types of weapons.

Each armor type is allowed four "peak" blocking frequency spreads to better represent the specific properties of the armor material. Incoming radiation (not particles or plasma) in these frequency ranges is adjusted by a factors unique to that frequency spread. For plasma, particles, and radiation outside of the specific frequency "spreads", a generic blocking factor is applied instead.

Blocking effects are determined separately for armor, terrain, and weather :

Armor Systems

- The frequency of the Advanced/Energy weapon is compared to the armor system's blocking capabilities. If the armor type does not block the incoming pulse, the armor has no effect.
- If the armor is capable of blocking the Advanced/Energy weapon type, the armor system's "Peak Blocking" frequencies and spread values are compared to the frequency of the incoming pulse. If this frequency falls in one of the ranges blocked by the armor, the energy is reduced appropriately by the applicable percentage specified for the armor system.
- If the incoming pulse frequency is outside of the armor ranges, the power is reduced using the armor system's generic blocking value for the type of weapon being used. This option is always used against particle and beam weapons, since they do not have a meaningful frequency.
- Armor degradation is always dependent on the thickness of armor being traversed by the energy/plasma/particle pulse.
- Armor system blocking values are set in the Armor Data Editor.

Terrain/Path Degradation

- Terrain degrades Advanced/Energy weapon beams only if the straight line path to the target passes through the terrain. To determine if this condition is met, the beam path elevation is compared to the absolute elevation of the terrain, taking into account its height above ground level (AGL).
- The actual distance the beam travels through the terrain (in 3-dimensions) is calculated, and compared to the "standard" distance which equals the size of one hex. This proportion is applied to the terrain's blocking value to arrive at the actual amount of blocking to apply.
- The power is reduced by the adjusted percentage.
- Terrain effects are set using the TEC editor.

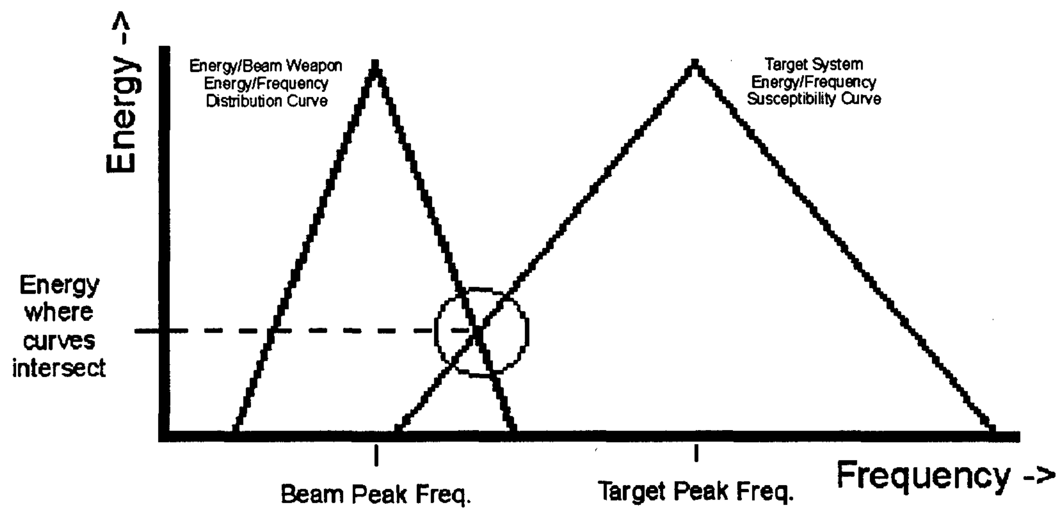
Weather/Atmospheric Degradation

- Atmospheric/weather degradation is calculated based on three factors:
  1) The weather/atmospheric conditions.
  2) The distance the pulse travels to the target.
  3) The weapon/pulse type.
- Degradation from the weather/atmosphere is inclusive - taking into account both blocking and scattering.
- Weather effects are set using the TEC editor.

EM Power / Frequency Curve Matching To Determine Target Damage

As was noted in the sections above, the effective EM power applied to a target will depend on the nature of both the incoming weapon radiation and the target. This section applies only to EM radiation - plasma and particle weapons ignore frequency effects and always impart their full energy (after being degraded as appropriate for atmospheric effects, armor, etc.).

To determine the effective energy absorbed by a target, the energy/frequency curves for the weapon and target are compared. This relationship is shown graphically below:



The "peak" of each curve is fixed by the weapon energy and the appropriate peak frequency values. The "width" of each curve is determined from the frequency "spread". The actual energy applied to the target (or "effective" energy), is determined by the point at which the curves intersect. If there are multiple intersections, the highest value is used exclusively.

In the diagram above, both curves are shown as straight lines. In cases where the energy distribution of the weapon is a standard "bell" curve, the energy weapon curve will appear to be more bell-shaped, with a rounded rather than sharp peak, and tapered ends. This is accomplished in the program by drawing the distribution as 5 straight lines on each side of the peak, with varying slopes. The effective energy, though, is still determined by the point at which the curves intersect.

Energy Weapon Effects

In this simulation, energy weapons in the electromagnetic portion of the spectrum cause effects on targets primarily by creating an electric current through the target medium. As such, almost any object made of conductive materials is potentially vulnerable to EM energy pulses. On the other hand, things made of non-conducting materials are virtually immune to their effects.

The simulation disregards other effects from EM radiation, such as electron displacement and disruption at the atomic or molecular level. While these effects are real (and are responsible for

causing sunburn, for example), their damage to electronic equipment is negligible compared to that from electric currents and arcs.

In real-life situations, the results of the impacting EM wave can be very complicated due to the target properties, shape and other conditions. However, at the most basic level, the "impacting" EM wave produces a duplicate wave in the target material. As with familiar AC (alternating current) household electricity, the wave induces voltage differences as it is conducted though the target. The maximum and minimum voltage values will be found at each "peak" and "valley" of the wave, respectively. The higher each peak (and lower each valley), the greater the voltage of the induced current. Since the voltage represents the "force" of the current, as the voltage increases so does the potential to damage the system. The "height" of each peak is known as the amplitude.

The second component of the current is the number of electrons actually being moved. This value is a function of the resistance of the material, and the applied voltage according to the equation $V = I \times R$ (where I is the current in Amperes, V is the voltage in Volts, and R is the resistance in Ohms).

The combination of voltage and resistance (of the target material) creates a current. Under the right conditions, the current can destroy or incapacitate sensitive electrical components of its own accord, simply by burning them out or erasing information that may be stored in them. The current can also damage components though secondary effects, such as creating heat, magnetism, or arcing.

The duration of the energy pulse is important in determining the damage since it represents how long the voltage and current are applied to the target. The longer the duration, the greater the probability of causing damage. However, these increases are not necessarily linear, and are limited even for long duration times. The reasoning here is that sensitive electronics components normally fail almost immediately once a certain threshold is reached. If the threshold is not reached, or if it is and the component survives, additional exposure to the current caused by the extended pulse duration will have less of an impact.

Plasma and particle weapons, on the other hand, cause damage by destroying the physical makeup of the target substance. In a simplification of the process, they "erode" the material at the atomic or molecular level. In the process, they can also create a great amount of heat in the target, and even change the chemical structure of the material, both of which can create internal chemical reactions and other secondary effects.

Unlike EM energy pulses, the duration of a plasma or particle beam pulse has a linear relationship to the damage probability; i.e., the probability is doubled if the pulse lasts 2 μs, tripled at 3 μs, and so on. The reason for this is that damage from these weapons is cumulative, and there is no "threshold" or steady state condition which is established as in the case of the electric current. The longer the beam stays on the target, the more of it is destroyed.

The simulation recognizes many different types of specific target components, each of which have unique susceptibilities and characteristics. In choosing these systems, the following general assumptions were made about what they physically represent as part of the overall weapons system, as well as how they are damaged. The following table summarizes these assumptions:

Type	Represents	Damage from EM is Caused by:
Radar	Radar transceiver and antenna coupled to amplification and analysis equipment.	Burning out or overloading internal electronic components or antenna amplifiers.
Ammunition	Missiles, shells, and other individual items of ordinance fired by a gun or launch system.	1) Explosion of filler or propellant materials by heat or "sparking off" the detonator. 2) Burning out or overloading internal guidance components, including sensors, radios, radars, and/or other electrical systems.
Gun/Launcher	The complete system used to fire a round of ammunition or a missile, including guidance systems, automatic loaders, and other associated components.	Overloading or burning out electrical components.
Communications (Weapons System)	Radios, data links, antennas, and other electronic equipment used for communication/control purposes.	Overloading or burning out electrical components or antennas.
Fire Control (Weapons System)	Target detection, acquisition, and control equipment including sights and internal data systems.	Overloading or burning out electrical or optical components.
Other Electronics (Weapons System)	ECM/ECCM systems, GPS links, and other internal weapons systems electronics not covered by another category.	Overloading or burning out electrical components.
PMD	Complete Point Missile Defense system including the detection system, electronic data analysis and command computer, and active response measures.	Overloading or burning out electrical or optical components, detonating or inactivating the response system.

4. Estimates of Technical Feasibility

Based on the results of simulated engagements using the software developed for Phase I, it is apparent that a full-featured computer model can be developed that completely meets the needs of the military. In particular, the results of both conventional (using penetrating projectiles) and advanced/energy weapons can be modeled to a reasonable degree of accuracy. Screen shots showing results of these aspects of the computer model are shown in Appendix A.

Additionally, based on HPS Simulations' previous combat simulation experience, these components can be seamlessly integrated into an overall simulated combat environment, which includes intangible factors (morale, training, etc.), environmental considerations, and C3I (communications, command, control, and intelligence/fog of war).

5. Personnel Involved

The following personnel contributed to the Phase I project:

Scott S. Hamilton: Research, database and model development, programming.
Gregory M. Smith: Research, weapon effect analysis.
John C. Kincaid: Research, database entry, testing.
Nicholas Bell: Weapon effect analysis, testing.
Joe Amoral: Artwork.
Dr. Michael A. Palmer: Research.

Appendix A: Screen Shots Showing Model/Computation Results

These screen shots illustrate some of the models developed in the Phase I project. The physical characteristics of the US M829A2 projectile were found in the Jane's Ammunition Handbook, 1998. The directed energy weapon data is completely hypothetical and is used for demonstration purposes only.

Distribution Statement A. Approved for public release; distribution is unlimited.

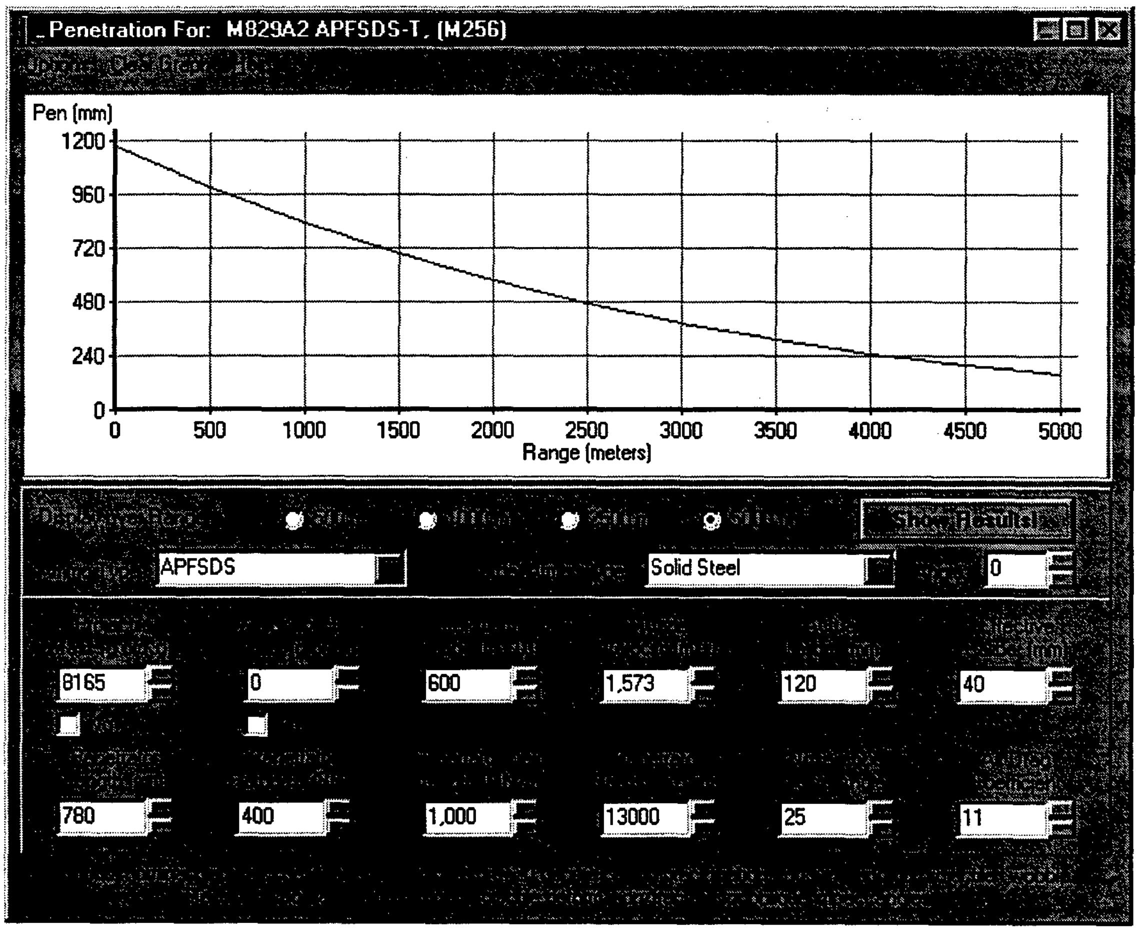


Figure A1: Calculated standard penetration vs. range graph for M-829A2 round fired by US M1 Abrams MBT. In addition to the projectile's characteristics, the penetration calculations also take into account target armor and enviromental factors.

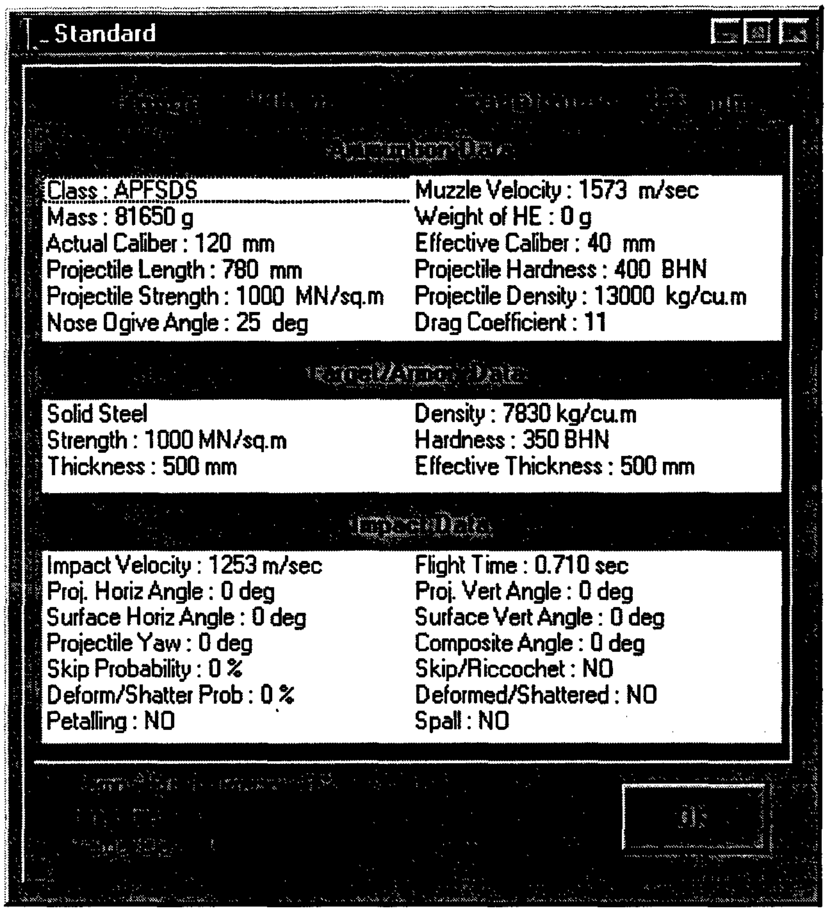
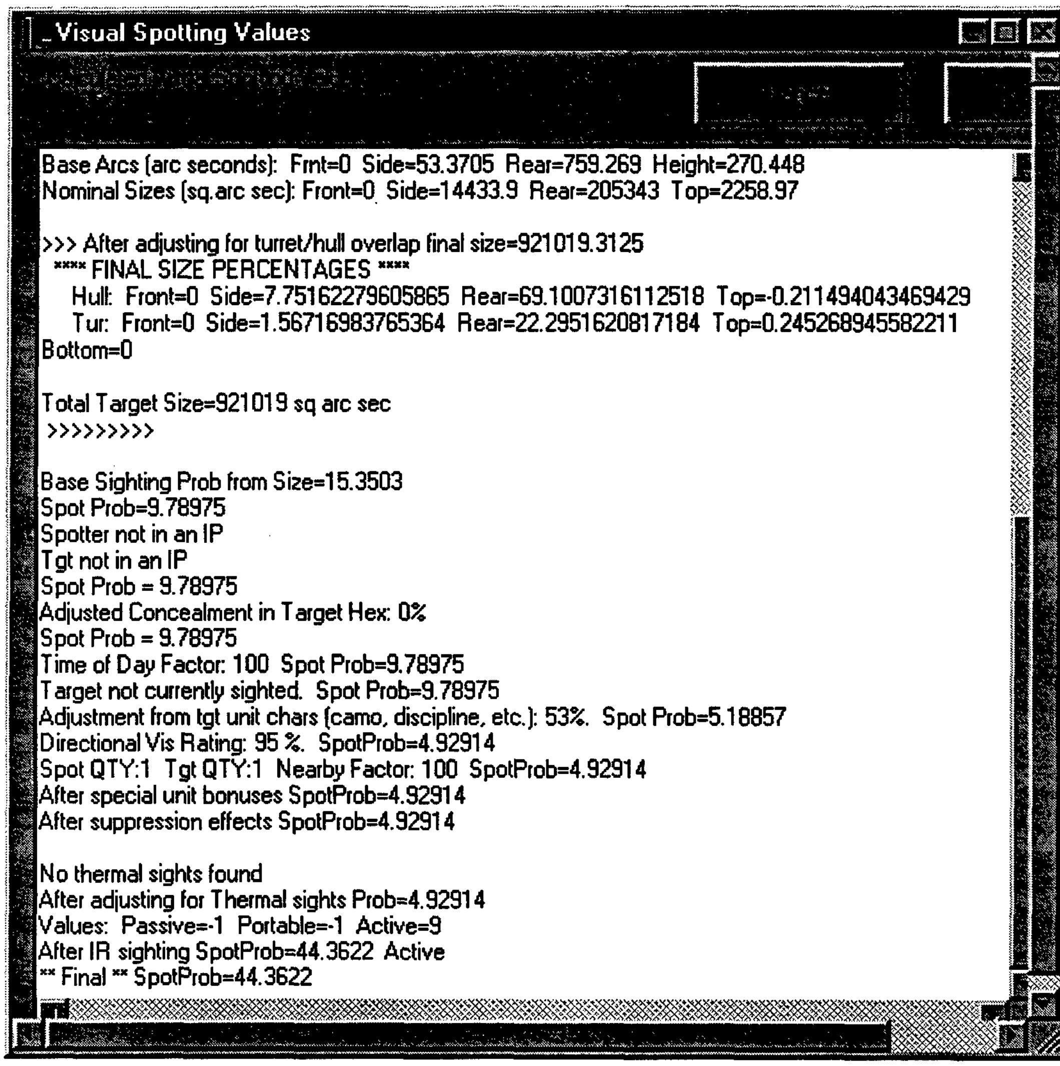


Figure A2: Detailed calculation results for M829A2 round impacting a steel target (from Figure A1, above) at 1000 meters.



Visual Spotting Values

Base Arcs (arc seconds): Frnt=0 Side=53.3705 Rear=759.269 Height=270.448
Nominal Sizes (sq.arc sec): Front=0 Side=14433.9 Rear=205343 Top=2258.97

>>> After adjusting for turret/hull overlap final size=921019.3125
**** FINAL SIZE PERCENTAGES ****
Hull: Front=0 Side=7.75162279605865 Rear=69.1007316112518 Top=-0.211494043469429
Tur: Front=0 Side=1.56716983765364 Rear=22.2951620817184 Top=0.245268945582211
Bottom=0

Total Target Size=921019 sq arc sec
>>>>>>>>>

Base Sighting Prob from Size=15.3503
Spot Prob=9.78975
Spotter not in an IP
Tgt not in an IP
Spot Prob = 9.78975
Adjusted Concealment in Target Hex: 0%
Spot Prob = 9.78975
Time of Day Factor: 100 Spot Prob=9.78975
Target not currently sighted. Spot Prob=9.78975
Adjustment from tgt unit chars (camo, discipline, etc.): 53%. Spot Prob=5.18857
Directional Vis Rating: 95 %. SpotProb=4.92914
Spot QTY:1 Tgt QTY:1 Nearby Factor: 100 SpotProb=4.92914
After special unit bonuses SpotProb=4.92914
After suppression effects SpotProb=4.92914

No thermal sights found
After adjusting for Thermal sights Prob=4.92914
Values: Passive=-1 Portable=-1 Active=9
After IR sighting SpotProb=44.3622 Active
** Final ** SpotProb=44.3622

Figure A3: Final portion of the sighting results between two units showing many of the factors considered in the model.

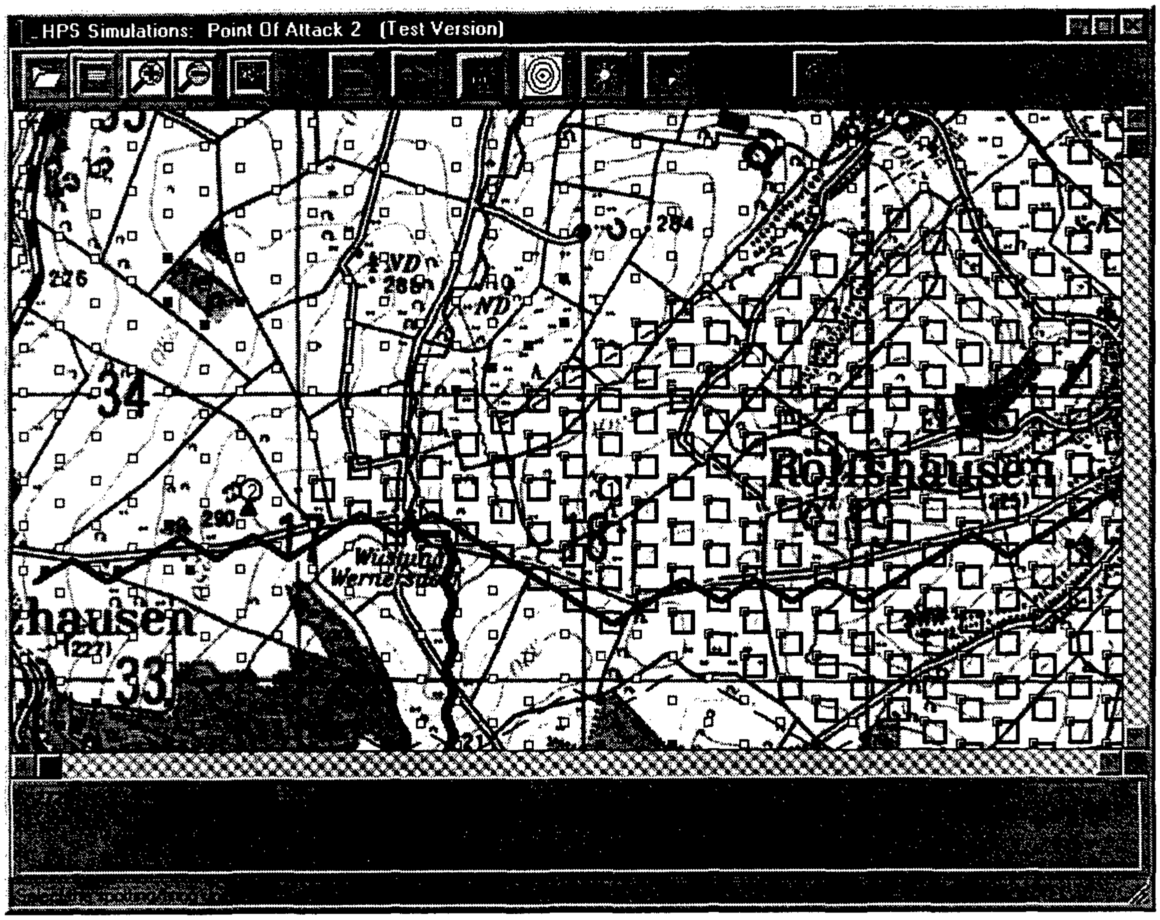


Figure A4: Hypothetical directed energy weapon attack. The weapon is detonated at point "2", facing East and at 500 meters above ground level (AGL). The weapon has an "arc" of +/- 40 degrees. The dark squares indicate the hexes which are affected by the energy. A US M2 is located at point "1" to act as a test target.

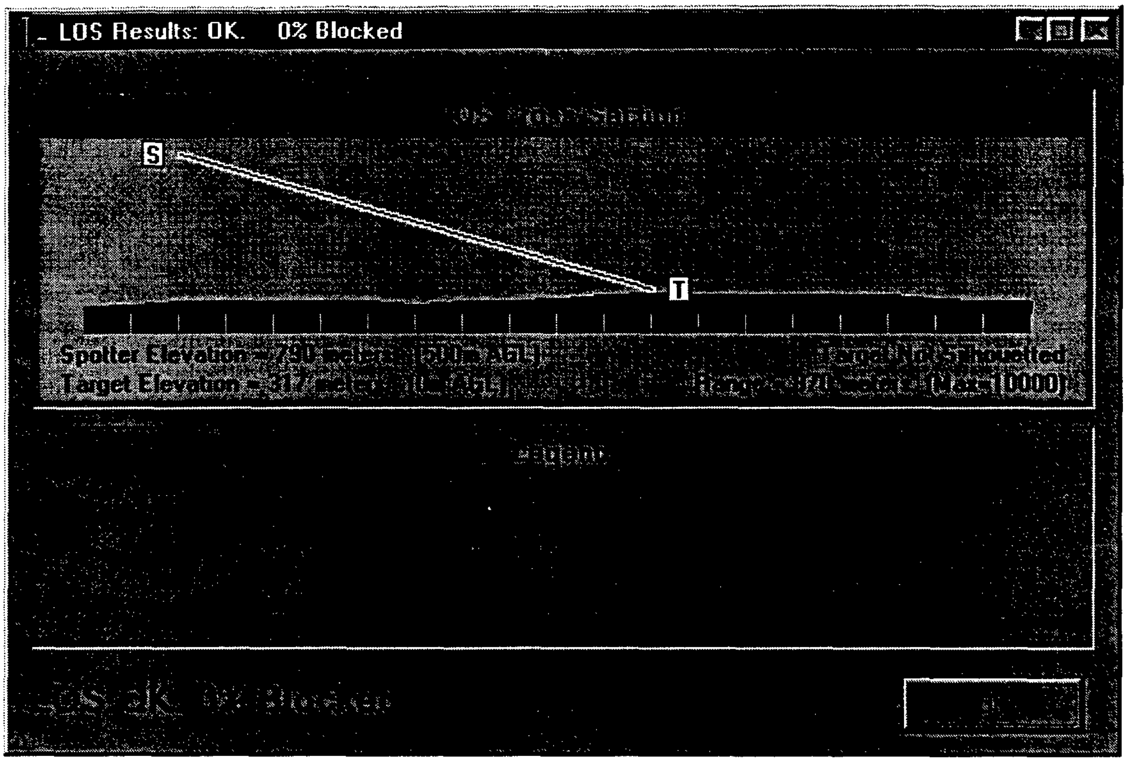


Figure A5: The Line Of Sight (LOS) between the energy weapon detonation point and the US M2 target. No terrain or other objects block the energy. However, energy may be absorbed by the atmosphere.

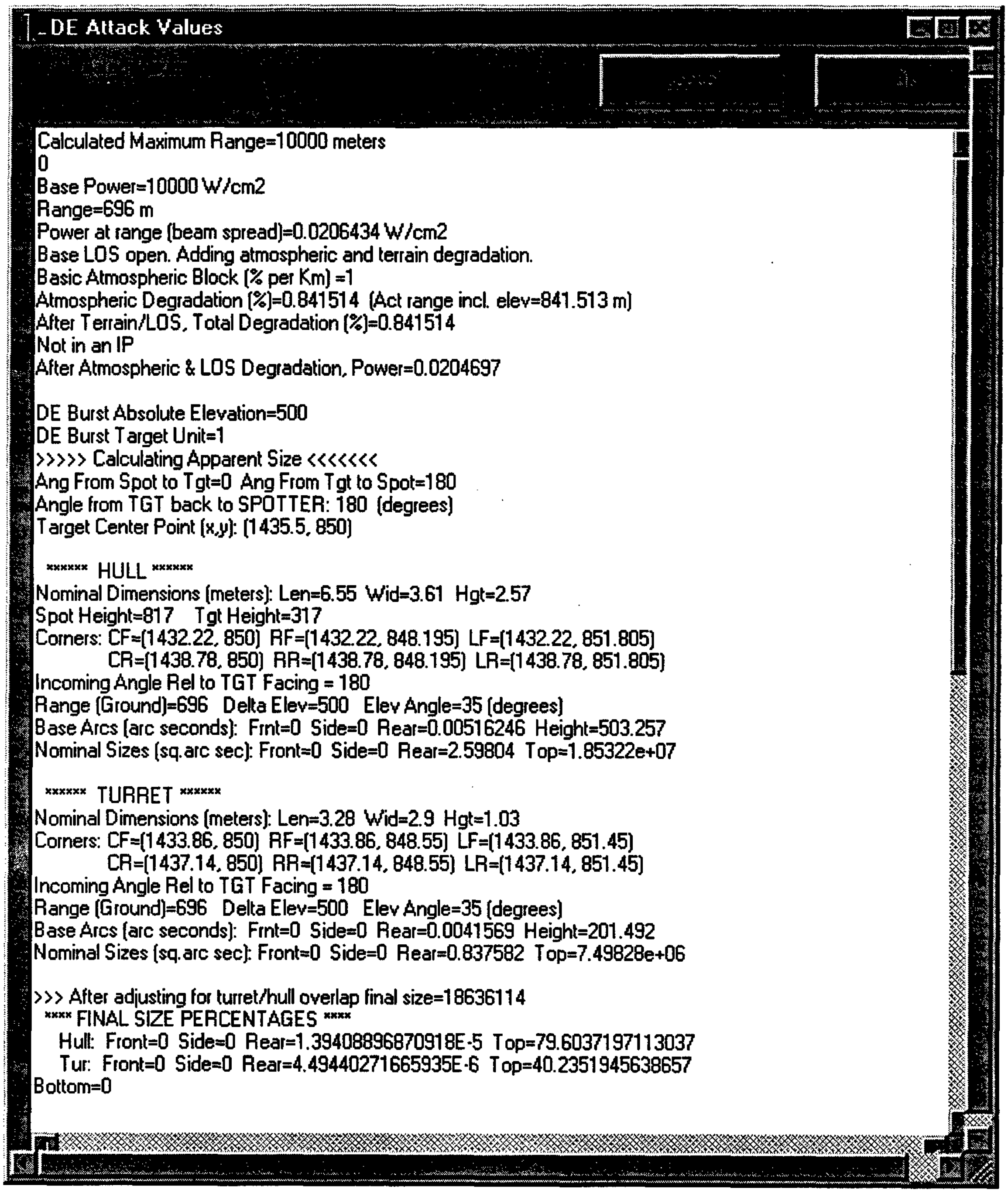


Figure A6: First page of results from the directed energy weapon. This shows degradation from the atmosphere as well as how all of the relevant angles and target sizes are calculated.

DE Attack Values

```
>>> After adjusting for turret/hull overlap final size=18636114
 **** FINAL SIZE PERCENTAGES ****
   Hull:  Front=0  Side=0  Rear=1.39408896870918E-5  Top=79.6037197113037
   Tur:  Front=0  Side=0  Rear=4.49440271665935E-6  Top=40.2351945638657
Bottom=0


** Ready to Calculate Armor Blocking Values **
Armor Blocking factor (% per mm)=0.498488
Armor/Thickness Degradation (%)=74.6693
Wide arc hits entire tgt.Total Degradation=74.6693%
After Armor Degradation, Power=0.00518511


Checking COMMO System for energy damage
Peak Freq: 10000000000 Hz   Range:-111136768 to 20111136768 Hz   (Spread=20222273536 Hz)
Getting curve intercepts=>
DE Freq=1.000E+09 DE Spread=5.000E+05 DE Power=1.000E+04
Sys Freq=1.000E+10 Sys Spread=5.056E+09
Line intercept frequency:0 Hz    Power=0 W/cm2
No power overlap in commo damage freq range.

Checking Fire Control Systems for energy damage
Peak Freq: 1000000000 Hz   Range:-509634176 to 2509634176 Hz
Line intercept frequency:1000000000 Hz    Power=0.00518511468544602 W/cm2
Total Power (1200 cm2)=6.22214 W  Freq=1e+09  100% kill energy=10W  Kill Prob=91 Knocked out!

Checking Other Systems (PMD/Laser/Decoy) for energy damage
Getting curve intercepts=>
DE Freq=1.000E+09 DE Spread=5.000E+05 DE Power=1.000E+04
Sys Freq=1.000E+06 Sys Spread=5.000E+02
Line intercept frequency:0 Hz    Power=0 W/cm2
No power overlap in ammo damage freq range.
Getting curve intercepts=>
DE Freq=1.000E+09 DE Spread=5.000E+05 DE Power=1.000E+04
Sys Freq=1.000E+06 Sys Spread=5.000E+02
Line intercept frequency:0 Hz    Power=0 W/cm2
No power overlap in ammo damage freq range.
Getting curve intercepts=>
DE Freq=1.000E+09 DE Spread=5.000E+05 DE Power=1.000E+04
Sys Freq=1.000E+06 Sys Spread=5.000E+02
Line intercept frequency:0 Hz    Power=0 W/cm2
No power overlap in ammo damage freq range.
```

Figure A7: Second page of the directed energy weapon results on the M2 target. After being reduced for the vehicle's armor, the energy is determined to have knocked out the fire control system. Note that there is no “overlap” between the energy weapon frequency and the other M2 subsystems (“spread”).